ERC Working Papers in Economics 16/03
March / 2016

Estimating Cost Efficiency of Turkish Commercial Banks under Unobserved Heterogeneity with Stochastic Frontier Models

Hakan Güneş
Department of Economics, Middle East Technical University, Ankara, Turkey
E-mail: hgunes@metu.edu.tr
Phone: + (90) 312 210 3041

Dilem Yıldırım
Department of Economics, Middle East Technical University, Ankara, Turkey
E-mail: dilem@metu.edu.tr
Phone: + (90) 312 210 2019

Estimating Cost Efficiency of Turkish Commercial Banks under Unobserved Heterogeneity with Stochastic Frontier Models

HAKAN GÜNEŞ

Department of Economics, Middle East Technical University, 06531, Ankara, TURKEY

Email: hgunes@metu.edu.tr, Phone: +90 312 210 3041, Fax: +(90) 312 210 7964

DİLEM YILDIRIM

Department of Economics, Middle East Technical University, 06531, Ankara, TURKEY

Email: dilem@metu.edu.tr, Phone: +90 312 210 2019, Fax: +(90) 312 210 7964

Corresponding Author: Dilem YILDIRIM, dilem@metu.edu.tr, phone: +90 312 210 2019

Estimating Cost Efficiency of Turkish Commercial Banks under Unobserved Heterogeneity with Stochastic Frontier Models

Abstract

This study aims to investigate the cost efficiency of Turkish commercial banks over the restructuring period of the Turkish banking system, which coincides with the 2008 financial global crisis and the 2010 European sovereign debt crisis. To this end, within the stochastic frontier framework, we employ a modified version of the true fixed effect model of Greene (2005), where the unobserved bank heterogeneity is integrated in the inefficiency distribution at a mean level. To select the cost function with the most appropriate inefficiency correlates, we first adopt a search algorithm and then utilize the model averaging approach of Huang and Lai (2012) to verify that our results are not exposed to model selection bias. Overall, our empirical results reveal that cost efficiencies of Turkish banks have improved over time, with the effects of the 2008 and 2010 crises remaining rather limited. Furthermore, not only the cost efficiency scores but also impacts of the crises on those scores appear to vary with regard to bank size and ownership structure, in accordance with much of the existing literature.

Keywords: Stochastic Frontier, Cost Efficiency, Turkish commercial banks, Panel Data

JEL classification numbers: C23, C24, D21, G21, G28

1. Introduction

A stable and efficient banking system is quite important for economic growth and welfare especially for emerging countries like Turkey where the banking sector is the backbone of the economy. The banking system in Turkey has experienced a fundamental change due to the far-reaching reforms implemented in the aftermath of the 2001 local financial crisis. The year of 2001 could well be named as a milestone for the Turkish banking sector. In that year, the banking sector faced with a very deep and devastating crisis and a substantial increase in the non-performing loans due to the skyrocketed interest and exchange rates, inadequate level of funding, maturity mismatch, insufficient risk management practices and bad governance. Subsequent to the 2001 financial crisis, a comprehensive restructuring program was implemented with the aims of strengthening state and private banks, solving the problems of troubled banks, addressing regularity and supervisory deficiencies and improving competition as well as efficiency. With the gradual implementation of the reform package, the Turkish banking sector experienced a rapid and stable financial deepening process during 2002-2007. More recently, the Turkish economy was severely affected by the 2008 global crisis similar to all other emerging economies. The banking sector however, was relatively less affected compared to the banking sectors in many other emerging countries, which was owed to the reforms adopted successfully after the 2001 crisis to strength the Turkish banking system.

In this context, this study aims to measure the efficiency of Turkish commercial banks. Although the efficiency of the banking system has been analyzed in numerous studies for transition economies and EU countries both in terms of cross-sectional differences and time dynamics (e.g. Kumbhakar and Wang, 2007; Du and Girma, 2011; Koetter and Wedow, 2010; Manlagnit, 2011; Almanidis, 2013; Carvallo and Kasman, 2005; Kasman and Yildirim, 2006; Poghosyan and Kumbhakar, 2010; Williams, 2012) [1], the literature on the efficiency of the banking sector in developing countries such as Turkey is relatively thin. Onis (1995) and Ertugrul and Zaim (1999) are among the first to investigate the effect of financial liberalization on the efficiency of Turkish banks. Adapting the data envelopment analysis (DEA), a non-parametric approach introduced by Charnes, Cooper and Rhodes (1978), they reveal that the financial liberalization that took place in the late 1980s led to an increase in the efficiency of

[1] See Banerjee (2012) for an excellent review of the bank efficiency literature.

Turkish banks. A similar finding is observed by Demir et al. (2005) through the stochastic frontier approach. They deduce that the efficiency gain is more prominent for the larger banks, which might be due to the government's encouragement for bank acquisitions and mergers in the post-liberalization period. Yildirim (2002) and Denizer et al. (2007), on the other hand, observe that the liberalization did not provide the anticipated efficiency gains in Turkish banks. Using the DEA approach, they find that efficiency scores do not display consistent increases in the post-liberalization environment probably due to the macroeconomic instability. Isik and Hassan (2002) adopt both a non-parametric and parametric approach to investigate the efficiency of Turkish banks over the period 1988-1996. Similar to Yildirim (2002) and Denizer et al. (2007), their findings point to a significant inefficiency problem, which displays no substantial improvement after the financial liberalization reforms. Kasman (2002) adopt the stochastic frontier approach to investigate the efficiency over the period 1988-1998 and validates the finding of Isik and Hassan (2002) in terms of the significant inefficiency problem of the Turkish banking system.

The studies by Fukuyama and Matousek (2011), Ozkan-Gunay (2012) and Assaf et al. (2013) focus on the evolution of the bank efficiency in the aftermath of the local and global financial crises. Fukuyama and Matousek (2011) utilize a two-stage network model to analyze the efficiency of the Turkish banking system over the period from 1992 to 2007. Their findings indicate that the restructuring program adopted in 2001 has a positive effect on bank efficiency over the period 2001-2004. However, after 2004 when the restructuring reforms are formally ended, the picture has changed and a gradual annual decline is observed in bank efficiency levels. Ozkan-Gunay (2012), on the other hand, reveal a substantial and more importantly a gradual improvement in the bank efficiency following the restructuring program by applying the DEA approach to the dataset spanning from 2002-2009. Assaf et al. (2013) analyze the efficiency of Turkish banks by adopting a Bayesian stochastic frontier approach. Relatively similar to Fukuyama and Matousek (2011), their analysis indicates a decline in the efficiency of Turkish banks over the period 2002-2010. Furthermore, it is seen that the annual decline in efficiency becomes more prominent in 2009 and 2010 due to the 2008 global financial crisis.

Our study aims to measure the cost efficiency[2] of 22 Turkish commercial banks over the period of 2003Q1-2015Q3. The use of the longest time period allowed by data availability is important to observe the temporal movement of the efficiency of Turkish banks. More specifically, with our data we will be able to provide a long-term empirical assessment of the effectiveness of the restructuring reforms implemented after the 2001 crisis. Although increasing bank efficiency was one of the crucial objectives of the restructuring program, whether it is achieved or not is still controversial in the empirical literature. Moreover, although it is partially investigated by Assaf et al. (2013) over the sample 2002-2010, extension of the sample period to 2015 enables us further to attain more reliable inference on how the 2008 global financial crisis has affected the efficiency of Turkish banks. As underlined by Assaf et al. (2013), the time period they examined is not long enough to propose direct conclusions about the impact of the 2008 financial crisis on Turkish banks and future stability of the banking sector. Finally, our dataset allow us to investigate the impacts of the 2010 European sovereign debt crisis on the efficiency of commercial banks in Turkey, which has not been examined so far to the best of our knowledge.

Methodologically, unlike the previous studies for Turkey, we employ a modified version of the true fixed effect model of Greene (2005), where the unobserved bank heterogeneity is embedded in the inefficiency distribution at a mean level. Moreover, being aware of the fact that the efficiency analysis could be quite sensitive to the choice of the inefficiency determinants, we adopt an exhaustive search algorithm to specify the cost frontier function with the most appropriate inefficiency correlates. Furthermore, to circumvent any possible problems, including the model selection and omitted variable biases that may arise from relying on only the single (best) model, we perform the model-averaging approach of Huang and Lai (2012).

The rest of the paper is organized as follows. Chapter 2 provides a brief overview of the Turkish banking sector. Chapter 3 discusses the econometric methodology we implement and Chapter 4 describes the data in detail. Substantive empirical findings are discussed in Chapter 5 and finally Chapter 6 concludes the study.

[2] There are different types of efficiency concepts. While technical efficiency measures the ability of a firm to obtain maximal output using fixed level of inputs, allocative efficiency implies that a firm uses its inputs in the optimal proportions to produce fixed level of output. In our study we focus on the cost efficiency, which combines both technical and allocative efficiencies.

2. A Brief Overview of the Turkish Banking Sector

In the last two decades, the Turkish economy has witnessed several financial crises that were caused mainly by poor macroeconomic conditions and a fragile banking system. 1990s were the starting era of structural problems in the banking system, which had experienced legal, structural and institutional changes with the financial liberalization program adopted in 1980s. In the early 1980s the Turkish government launched a liberalization program that aimed to generate a free market economy. In this context, the banking system was deregulated, restrictions regarding market entry and interest rates were eliminated. As expected, the launched program increased the competition with the entries of new domestic and foreign banks, which in turn led to a wide variety of banking services, including capital market operations, purchase of government debt securities and Treasury bonds.

In 1990s, banks decreased the amount of traditional banking activities in their portfolios and started to invest more and more in risk free government debt instruments. In other words, the banking sector became the main instrument of government financing by transferring short-term borrowing from domestic and foreign depositors and investors to the government (Akın et al., 2009). High government debt with low levels of maturity eventually led to an environment characterized by high levels of inflation and real interest rates. Increasing risks in the financial system lowered the average maturity of savings and triggered excessively high loan interest rates. The economic and financial conditions deteriorated further due to domestic political instabilities and the Asian and Russian crises in 1997 and 1998, which negatively affected the confidence of foreign investors in Turkey and lowered capital inflows as well as international borrowing opportunities. Hence, due to inadequate level of funding, maturity mismatch, high amount of nonperforming loans, insufficient risk management practices and bad governance, the Turkish banking system experienced a systemic crisis which reached its peak in 2001 (BRSA, 2001). With the 2001 crisis, several banks went bankrupt and transferred to the Saving Deposits Insurance Fund (SDIF), the Turkish financial market ceased to function, economic activities slumped and the economy contracted drastically.

After the 2001 crisis many reforms were implemented in a timely manner by the Turkish authorities to retrain the impact of the crisis on the structure of the economy and to drive the economy into a more sound and stable pattern in the long term. The bank restructuring program

initiated by the Banking Regulation and Supervision Agency was the vital part of these reforms. The program rested on four main pillars: financial restructuring of the state banks, implementation of measures to facilitate the participation of the private capital to strength the private banking system, prompt resolution of the SDIF banks and taking measures for prudential regulation and supervision of the banking sector. With this program substantial achievements were made in the Turkish banking system. More specifically, short-term liabilities of the state banks were terminated and they were reinforced through mergers and privatized, some privately owned banks were provided with capital support, SDIF banks were liquidated and merged with or transferred to another bank. This new regulations scheme culminated into a low inflationary environment with low market interest rates and high rate of economic growth. Following this restructuring process, the Turkish banking system showed a rapid growth performance with high profit levels by international standards during the period 2002-2008.

In 2008, the subprime mortgage crisis, which became visible during 2007, hit the real economy of all countries around the world. It led to the collapse of several major financial institutions, disruption in the flow of credit to businesses and consumers and finally a severe global recession. Due to the high level of integration with the world economy and dependency on the external market, the Turkish economy was severely affected by the 2008 global crisis similar to the other emerging market economies. The financial position of Turkish banks, however, has not deteriorated to the same extent as was the case with banks in other emerging economies. This was mainly due to the comprehensive reforms adopted successfully after the 2001 crisis to strength the Turkish banking system (Aysan and Ermisoglu, 2013b). Nevertheless, some negative effects of the global financial crisis were observed in the banking system in Turkey. Following the 2008 global crisis, concerns on the high default rates led to an increase in the cost of international funds for banks, which in turn caused a reduction in the credit supply. Meanwhile, the slowdown of the economic activity resulted in a fall in the demand for loans. Overall, the banking sector has faced with a substantial decrease in the credit growth, deterioration in asset quality and an increase in non-performing loans. The extraordinary measures taken abroad and in Turkey, including decreasing interest rates liquidity provision by the central bank, restored the confidence in the financial markets. Subsequently, the deterioration in the nonperforming loans stopped and the asset quality of the banking sector improved.

Although led to no major impairment in Turkish economy, the 2008 global crisis evolved into a debt crisis in Europe with accumulation of external debts' of governments to rescue troubled banks that had invested heavily in the US mortgage market. The crisis started in Greece where the sovereign debt burden became unsustainable and then spread to other member countries. Turkey was affected by the 2010 European debt crisis mainly through the trade channel as its major trade partners are EU countries. For the Turkish banking system, however, the effects of the crisis remained rather limited due to the lessons learned from the 2001 financial crisis and having relatively weaker financial ties to Europe compared to those of Eastern and Central Europe countries (Aysan and Ermisoglu, 2013a). To be more specific, the low share of foreigners in the Turkish banking sector makes it less financially dependent upon Europe, as compared to other European countries.

3. Methodology

This chapter describes the stochastic frontier approach we adopt to measure the cost efficiency of Turkish banks[3]. As such, we utilize the commonly used cost function approach due to outputs in the banking sector being exogenous (demand determined) and not storable. Furthermore, as underlined by Kumbhakar and Lovell (2000), the cost function approach enables us to handle with the multiple outputs problem in measuring cost efficiency. The stochastic cost frontier function, introduced independently by Aigner et al. (1977) and Meeusen and van den Broeck (1977), can be expressed as:

$$C_{it} = C\left(y_{it}, w_{it}; \beta\right)\exp\left(u_{it}\right)\exp\left(v_{it}\right) \tag{1}$$

where C_{it} is the observed total cost of the bank i $\left(i = 1, 2..., N\right)$ in the period t $\left(t = 1, 2..., T\right)$, y_{it} represents its output, w_{it} is a vector of input prices, β is a vector of parameters, u_{it} is the non-negative error term representing inefficiency and v_{it} is the i.i.d $N\left(0, \sigma_v^{\,2}\right)$ random errors being

[3]In addition to the stochastic frontier approach, there is another popular technique used in the literature to evaluate the cost efficiency: the nonparametric data envelope analysis (DEA). The DEA approach employs a linear programming method to construct the efficient frontier from the observed input-output ratios as a piecewise linear combination of the most efficient units. Its major disadvantage is that it does not allow for random fluctuations and associates all deviations from the estimated frontier to inefficiency, which makes the observed efficiency scores to be quite sensitive to outliers and shocks.

independently distributed of the u_{it} and standing for possible measurement errors and exogenous random shocks received by the cost function. Under this methodology, a commercial bank is considered as inefficient if its costs are higher than those of an efficient commercial bank producing the same output under the same existing conditions. More specifically, the model implies that a bank's observed total cost might deviate from the cost-efficient frontier, i.e., minimum or best-practice cost frontier, due to some uncontrollable random factors and bank's inefficiency.

The literature offers several different approaches to model the non-negative inefficiency component u_{it}. This study follows a modified version of the true fixed effect model of Greene (2005). In its original form, the true fixed effect model treats time-invariant bank specific heterogeneity and time varying inefficiency separately by integrating bank specific dummy variables into the cost function. As a result it manages to distinguish between unobserved heterogeneity and inefficiency. In this respect, it differs from the traditional estimators for stochastic frontier in a panel set-up which cannot estimate the firm's fixed effects separately from the time varying efficiency scores (Cornwell et al., 1990; Kumbhakar, 1990; Battese and Coelli, 1995). However, as underlined by Greene (2004), integrating the cost function with bank specific dummy variables, might lead to an overspecified cost function, which in turn may induce underestimation of inefficiencies. To circumvent such an underestimation problem, one can follow an alternative approach proposed by Greene (2004) and have the heterogeneity reside in the inefficiency distribution. In this way, it is possible to account for unobserved bank specific heterogeneity at mean level in cost efficiencies. In our analysis, following the suggestion of Greene (2004), we embed the heterogenity in the inefficiency distribution and define the time-varying inefficiency effect u_{it} as:

$$u_{it} = \left| N\left(\mu_i, \sigma_u^2\right) \right| \qquad (2)$$

$$\mu_i = \xi_i + \eta' z_{it}$$

where z_{it} is the vector of explanatory variables that may influence bank efficiency, η is the vector of parameters to be estimated and ξ_i is the bank specific intercept term placed to account for time-invariant bank specific heterogeneity and σ_u^2 is the variance of inefficiency. Obviously, with this specification u_{it} is assumed to follow a truncated-normal distribution with

heterogeneous mean across bank $\mu_i = \xi_i + \eta' z_{it}$ [4]. Given the representations in (1) and (2), the cost efficiency for an individual bank can be defined as the ratio of the cost of the best practice firm having zero inefficiency and the cost of that bank. More specifically, the cost efficiency for the *i-th* bank at the *t-th* observation can be expressed as:

$$CE_{it} = \exp(-u_{it}) \tag{3}$$

which ensures that the cost efficiency is bounded between zero and one.

To continue with estimation, we need to specify an appropriate functional form for the cost function in (1). Being in line with the studies, Mester (1997), El-Gamal and Inanoglu (2005), Bos, Koetter, Kolari and Kool (2009), Koetter and Wedow (2010), Williams (2012) and Almanidis (2013), we employ a flexible translog cost function to calculate efficiency of each individual bank.[5] Imposing translog functional form for the cost frontier function yields the following equation:

$$\begin{aligned}
\ln\left(\frac{C_{it}}{w_{2it}}\right) = {} & \beta_0 + \sum_j \beta_j \ln y_{jit} + \sum_k \alpha_k \ln\left(\frac{w_{kit}}{w_{2it}}\right) + \frac{1}{2}\sum_j\sum_l \delta_{jl} \ln y_{jit} \ln y_{lit} \\
& + \frac{1}{2}\sum_k\sum_p \phi_{kp} \ln\left(\frac{w_{kit}}{w_{2it}}\right)\ln\left(\frac{w_{pit}}{w_{2it}}\right) + \frac{1}{2}\sum_j\sum_k \phi_{jk} \ln y_{jit} \ln\left(\frac{w_{kit}}{w_{2it}}\right) \\
& + \psi_1 \ln q_{it} + \frac{1}{2}\psi_2 \ln q_{it}^2 + \sum_j \psi_{3j} \ln y_{jit} \ln q_{it} + \sum_k \psi_{4k} \ln\left(\frac{w_{kit}}{w_{2it}}\right)\ln q_{it} \\
& + \theta_1 t + \theta_2 t^2 + \sum_j \theta_{3j} \ln y_{jit} t + \sum_k \theta_{4k} \ln\left(\frac{w_{kit}}{w_{2it}}\right) t + \theta_5 \ln q_{it} t + u_{it} + v_{it}
\end{aligned} \tag{4}$$

where $\ln C_{it}$ is the natural logarithm of the total cost of the *i*th bank in the period *t*, $\ln y_{jit}$ represents the natural logarithm of its *j*th output, $\ln w_{kit}$ is the natural logarithm of its *k*th input price, $\ln q_{it}$ denotes its equity being used to control observable heterogeneity among banks, t denotes time which is included to capture non-neutral technological changes and $u_{it} = z_{it}\eta + w_{it}$ as discussed earlier. To be consistent with the economic theory, which requires the cost function

[4] Some of the studies, including Kasman (2002), Du and Girma (2011) and Isik and Hassan (2002b), impose the half-normal assumption on the inefficiencies. However, as proposed by Greene (1990), such an assumption might lead most banks to be clustered near full efficiency.

[5] There are two commonly used functional forms in the recent literature, translog and Fourier. Altough McAllister and McManus (1993) and Mitchell and Onvural (1996) rejects the translog specification due to the possible bias that may arise from using a sample of banks with different size and product mix, Berger and Mester (1997) observe that the translog and Forurier specifications of cost functions produce almost same results in terms of average efficiency and dispersion of the measured efficiency.

to be monotonically increasing in input prices and outputs and to be concave in input prices, we imposed the regularity conditions, symmetry and linear homogeneity in input prices. The condition of symmetry requires:

$$\delta_{jl} = \delta_{lj} \ \forall\, j,l \qquad \varphi_{kp} = \varphi_{pk} \ \forall\, k,p \quad \text{and} \quad \phi_{jk} = \phi_{kj} \ \forall\, j,k$$

The linear homogeneity restriction, on the other hand, is ensured by normalizing costs and input prices using one of the input price $\left(w_{2it}\right)$.

Once the translog cost function (4) is specified, parameters of the cost function and the inefficiency model (2) are estimated by following the one-step maximum likelihood estimation (MLE) method of Greene (2005), where the likelihood function is formed with the parametrizations $\lambda = \dfrac{\sigma_u}{\sigma_v}$ and $\sigma = \sqrt{\sigma_u^2 + \sigma_v^2}$ [6]. This one step estimation approach allows for simultaneous estimation of the stochastic cost function and identification of the inefficiency correlates. Unlike the two-stage estimation procedure of Mesters (1996), it accounts for the possible correlation between the variables affecting the cost function and the correlates of the efficiency, which in turn eliminates any underestimation and bias problem[7]. Following estimation of the parameters, bank-specific efficiency scores are computed using the Jondrow et al. (1982) formula.

4. Data

Our dataset is compiled from the balance sheets and income statements of 22 commercial (deposit) banks operating in Turkey over the period 2003Q1-2015Q3, totaling 1120 observations[8]. Non-deposit banks, such as development and investment banks are excluded from our sample due to their functional differences from deposit banks. The assets of 22 commercial banks account for approximately 95% and 92%, on average, of the total assets of the whole commercial banking system and the domestic banking system, respectively. The banks are not homogenous with respect to their ownership status; that is of our 22 commercial banks 3 are

[6] See Greene (2005) for further details of the one-step MLE estimation procedure.
[7] See Wang and Schmidt (2002) for a detailed discussion on the advantages of the one-step simultaneous estimation.
[8] Balance sheet and income statement data is obtained from the database of The Banks Association of Turkey.

state-owned, 12 are privately-owned domestic and 10 are foreign banks. State-owned, domestic private and foreign banks are defined as those with more than 50 percent of state, private domestic and foreign ownerships, respectively. The banks we analyze differ with regard to their scales as well. In fact, it is possible to divide the banks into three groups according to their market shares: small banks (banks having market share of less than 1 percent), medium-sized banks (banks having market share of between 1 and 8 percent) and large banks (banks having market share of more than 8 percent). Based on this classification, we have 7 large, 5 medium scaled and 10 small banks in our sample.

Obviously, definition or identification of inputs and outputs of a bank is highly crucial to the measurement of its efficiency. Although there is no consensus on the explicit definition of banks' inputs and outputs, three competing approaches used in empirical literature are the intermediation approach, production approach and the value-added approach[9]. An important difference between them involves the treatment of deposits, which have both input and output characteristics. The intermediation approach proposed by Sealy and Lindley (1977) views banks as financial intermediaries using capital, labor, deposits and all other borrowed funds to produce loans and other earning assets. In other words, considering deposits as inputs, this approach describes the banking activities as transforming the money collected from depositors into the money lent borrowers. The production approach considers deposits as outputs and describes the banking activities as producing deposits and loans using traditional production factors, capital, labor, land and materials. Under the value-added approach of Berger and Humphrey (1992), on the other hand, deposits are specified as both inputs and outputs of banks in the cost functions. As noted by Berger and Humphrey (1997) the production approach is more suitable for evaluating the efficiency of bank branches due to the focus of the approach being on the operating costs of banking. The intermediation approach, on the other hand, accounts for both operating and interest costs and therefore it is preferable when the main interest is on the evaluation of the entire bank efficiency and economic viability of banks. Since our main focus is on the assessment of the overall efficiency, we apply the intermediation approach being in line with other empirical studies for emerging countries (e.g. Chen, 2002; Yildirim, 2002; Wang and Kumbhakar. 2009; Manlagnit, 2011; Fukuyama and Matousek, 2011; Assaf et al., 2013).

[9] See Berger and Humphrey (1997) and Kauko (2009) for an extensive discussion of these approaches.

In this sense, the total cost $(\ln C)$ in the model (4) is defined as the sum of interest and non-interest expenses, with the latter referring to the sum of provision of loan losses and other operating expenses. Regarding the outputs and inputs in (4), we have two outputs, total loans (y_1) and total securities (y_2). The two input prices are price of physical capital and labor (w_1), measured by the ratio of non-interest expenses to total assets, and price of loanable funds (w_2), defined as the ratio of total interest expenses to total deposits. Unfortunately, we are not able to use two separate input prices for physical capital and labor due to unavailability of the quarterly data for personnel expenses over the period 2003Q1-2005Q2. To avoid the unbalanced data problem, we augment these two prices and calculate a common price, as in Hasan and Marton (2003) and Kasman and Yildirim (2006). Furthermore, being aware of the fact that inflation might have an adverse effect on our analysis and it could lead to a distortion in comparison of our results over the study period, all input and output prices are expressed in US dollars, being in line with Fukuyama and Matousek (2011) and Asaf et al. (2013). This approach is simply a direct adjustment of the variables for inflation to minimize bias in our results.

Turning to the inefficiency determinants (z_i), our potential efficiency correlates are intermediation ratio, deposit-to-liability ratio, loan loss provision ratio, capital ratio, liquidity ratio and finally natural logarithm of total assets. Intermediation ratio defined as the ratio of loans to deposits is included to capture the differences of banks' ability to convert deposits into loans, as in Kasman and Yildirim (2006) and Manlagnit (2011). It is hypothesized that a bank with higher intermediation ratio would be more efficient, suggesting an inverse relationship between inefficiency and intermediation ratio. Similar to Malangit (2011) and Amidu and Wolfe (2013), we use deposit-to-liability ratio as a measure of banks' funding structure and expect the ratio to have a negative impact on inefficiency. Loan loss provision ratio measured by provisions for loan losses over total loans is employed to proxy for default risk or loan quality following Mester (1996) and Altunbas et al. (2001). As noted by Rao (2005), an inefficient bank with high costs would have more problem loans, implying a positive correlation between loan loss provisioning and operating costs. This indicates lower cost-efficient operations and hence, a negative sign is expected on the coefficient of loan loss provision ratio. Capital ratio measured by equity over total assets is included to control for the regularity conditions. An inverse relationship is expected between inefficiency and capital ratio since a higher capital ratio might

lead banks to be perceived as less risky and therefore they can borrow at lower interest rates and have lower costs (Fries and Taci, 2005). Liquidity ratio defined as the ratio of liquid assets to deposits and short-term funding controls liquidity risk of banks. While lack of liquidity may force banks to borrow funds at excessive cost, it is obvious that holding liquid has an opportunity cost of higher returns (Rao, 2005 and Ben-Khedhiri et al., 2011). Due to this confliction, we do not have priori expectations regarding the direction of the effect of liquidity ratio on efficiency. Finally, we incorporate the natural logarithm of total assets as a proxy for bank size to control for the impact of scale bias on efficiency, as in Hao et al. (2001) and Banker et al. (2010). Table 1 presents the summary of definitions of all variables included in the cost frontier function along with their descriptive statistics.

Table 1: Descriptive Statistics of the Variables

	Definition	*Mean*	*Standard Deviation*
Dependent variable			
Total cost (C)	Interest expense + Noninterest expense (USD thousands)	503,021	578,590
Cost frontier			
Outputs			
Total Loans (y_1)	Short term loans + Long term loans + Loans under follow up - Specific provisions (USD thousands)	11,673,994	16,026,066
Other earning assets (y_2)	Trading securities + Money market securities + Investment securities available for sale and held to maturity (USD thousands)	6,172,344	9,371,071
Input prices			
Price of labor and physical capital (w_1)	(Provision of loan losses or other receivables + Other operating expenses) / Total Assets	0.013	0.008
Price of loanable funds (w_2)	Interest expenses / Total deposits	0.025	0.011
Equity (q)	Owners' Equity	2,457,679	3,243,123
Inefficiency correlates			
Capital Ratio	Owners' Equity / Total Assets	0.129	0.052
Deposits/Liabilities	Total Deposits / Liabilities	0.621	0.120
Intermediation ratio	Total Loans / Total Deposits	0.882	0.347
Liquidity Ratio	Cash and Central Bank / Total Assets	0.072	0.040
Loan Loss Provision	Provision of Loan Losses / Total Loans	0.006	0.034
Logarithm of Total Assets	Natural Logarithm of Total Assets	15.718	1.778

5. Empirical Results

It is commonly acknowledged that the efficiency analysis is quite sensitive to the choice of the variables. Although there are certain limitations on variable selection due to the reliability of the data, the size of the data set studied could be also a determining factor. In this respect, while omitting relevant variables could result in misleading conclusions, the use of unnecessary variables might clutter the analysis and create interpretation difficulties. Hence, choosing the most influential explanatory variables is of particular interest in efficiency analysis. Although we specify a set of potential efficiency correlates including intermediation ratio, deposit-to-liability ratio, loan loss provision ratio, capital ratio, liquidity ratio and finally natural logarithm of total assets, we have no exact information regarding which ones should be included in the model.

To this end, this chapter discusses two different approaches we adopted to specify cost efficiency scores of Turkish commercial banks. While the first section describes empirical findings derived from a search algorithm designed to detect the most appropriate model, the subsequent section presents the results obtained from the model averaging approach of Huang and Lai (2012). Persistency of cost efficiency scores of commercial banks is investigated further in the final section.

5.1. Results from the Search Algorithm

To specify the cost frontier function with the most appropriate inefficiency correlates we adopt an exhaustive search algorithm aimed at minimizing the Akaike information criterion (AIC), which is a penalized likelihood criterion that trades off goodness of fit and parsimony. The algorithm starts with maximum likelihood estimation of the cost frontier function (4) by including all 6 inefficiency correlates and the corresponding AIC value is recorded. In the next step, the cost function is estimated by using all 5-subsets of inefficiency correlates and the model having minimum AIC is selected. This procedure continues with one correlate eliminated at each stage until only one is left. At the end, the algorithm selects 5 models out of 63 estimated cost functions and our preferred model is the one with the lowest value of AIC.

According to the algorithm, the cost frontier function with inefficiency correlates of intermediation ratio, capital ratio and the natural logarithm of total assets is chosen and the results that relate the measures of cost inefficiency to the specified correlates are reported in

Table 2[10]. Being consistent with our priori expectations, intermediation ratio, which captures the differences of banks' ability to convert deposits into loans, has a significant negative effect on the measured cost inefficiency. Corroborating the results of the earlier studies for transition economies, including of Fries and Taci (2005), Kasman and Kirbas-Kasman (2006) and Manlagnit (2011), this finding suggests that banks with higher ability to convert deposits to loans enjoy higher levels of efficiency. In accordance with our expectations, the capital ratio also appears to be significantly and negatively correlated with the cost inefficiency. As noted by Fries and Taci (2005) and Manlagnit (2011), well-capitalized banks are likely to be more efficient due to their high quality management and relatively less risky position, which enable them to borrow at lower costs. Regarding the effect of bank size, measured by the natural logarithm of total assets of banks, it appears that the cost inefficiency does not differ significantly with respect to bank size. Although found insignificant, the effect of bank size on measured cost efficiency scores will be explored later in more detail by plotting efficiency scores for small, medium-sized and large banks separately[11].

[10] The results from the estimated cost function are not presented here to conserve space but available upon request.

[11] We also conduct the generalized likelihood-ratio test of the null hypotheses that inefficiency effects are absent from the cost function, the inefficiency effects have a simple distribution (half-normal distribution), the inefficiency correlates we use have no significant effect on the cost inefficiencies and finally there is no heterogeneity in the cost inefficiencies. All four null hypotheses are strongly rejected, indicating that the specification of our model is perfectly adequate to measure the cost efficiency of Turkish banks. Test statistics are not reported here to conserve space but available upon request.

Table 2: Estimated Inefficiency Correlates

intercept	1.533***	ξ_{06}	0.263**	ξ_{15}	0.394**
	(0.283)		(0.102)		(0.159)
Capital Ratio	-1.801**	ξ_{07}	0.108	ξ_{16}	0.192**
	(0.798)		(0.085)		(0.093)
Intermediation Ratio	-0.709***	ξ_{08}	0.533**	ξ_{17}	0.289**
	(0.194)		(0.209)		(0.129)
Logarithm of Total Assets	-0.038	ξ_{09}	0.069	ξ_{18}	-0.044
	(0.065)		(0.083)		(0.074)
ξ_{01}	-0.086	ξ_{10}	0.155	ξ_{19}	0.144**
	(0.059)		(0.104)		(0.069)
ξ_{02}	0.434***	ξ_{11}	0.418**	ξ_{20}	-0.032
	(0.125)		(0.167)		(0.049)
ξ_{03}	0.315*	ξ_{12}	0.102	ξ_{21}	0.042
	(0.186)		(0.080)		(0.056)
ξ_{04}	0.462**	ξ_{13}	0.206		
	(0.228)		(0.130)		
ξ_{05}	0.371**	ξ_{14}	0.585*		
	(0.158)		(0.305)		

Notes: Numbers in parentheses are standard errors and (***) and (**) denote statistical significance at 1% and 5% significance levels, respectively.

Having discussed the inefficiency correlates, we proceed further with the estimated efficiency scores. The first panel of Figure 1 shows the weighted average of cost efficiency scores of commercial banks over the quarterly period 2003Q1-2015Q3. For convenience we also report them together with the corresponding standard errors in Table 3. The overall cost efficiency for the whole sample is found as approximately 87 percent, suggesting that an average commercial bank could improve its cost efficiency by approximately 13 percent to match its performance with the best practice bank producing same amount of goods and services with the same conditions. Alternatively, it implies that a typical bank wastes about 13 percent of its costs relative to the best practice bank. Turning to the efficiency scores over time, being in line with

Ozkan-Gunay (2012), the Figure clearly illustrates an upward trend in the cost efficiency scores during the post-crisis period 2003-2008, suggesting that the restructuring program fulfills its promise in terms of improving bank efficiency. Given that the Turkish banking system experienced a substantial improvement in terms of bank lending, asset quality and profitability during the post-crisis period as shown by Ozkan et al. (2014), this finding might not be surprising. Furthermore, the impact of the global financial crisis is also apparent from the deterioration of the efficiency scores after the third quarter of 2008. Over the following five quarters the cost efficiency declined by approximately 3 percentage points and finally reached its lowest level of 85 percent in the last quarter of 2009. Afterwards, the banking system started to recover and bounced back to its pre-crisis level of 88 percent in the last quarter of 2010. This reveals that the negative effect of the global crisis was felt but, unlike the findings of Assaf et al. (2013), a relatively quick recovery is observed at the end of 2010. The continued upward trend in cost efficiencies over the period 2011-2015 indicate further that the 2010 European debt crisis had no noticeable impact on the Turkish banking system in terms of average cost efficiency.

Table 3: Cost Efficiency Estimates from the Selected Model

Time	*Mean*	*Standard Deviation*	*Time*	*Mean*	*Standard Deviation*	*Time*	*Mean*	*Standard Deviation*
2003q1	0.771	0.061	2007q2	0.844	0.095	2011q3	0.893	0.085
2003q2	0.785	0.077	2007q3	0.862	0.095	2011q4	0.897	0.085
2003q3	0.783	0.067	2007q4	0.869	0.095	2012q1	0.890	0.085
2003q4	0.794	0.074	2008q1	0.873	0.098	2012q2	0.900	0.089
2004q1	0.815	0.095	2008q2	0.873	0.099	2012q3	0.903	0.087
2004q2	0.811	0.087	2008q3	0.884	0.097	2012q4	0.913	0.089
2004q3	0.817	0.093	2008q4	0.859	0.092	2013q1	0.916	0.088
2004q4	0.820	0.099	2009q1	0.857	0.092	2013q2	0.924	0.080
2005q1	0.831	0.098	2009q2	0.858	0.089	2013q3	0.916	0.075
2005q2	0.831	0.091	2009q3	0.861	0.083	2013q4	0.913	0.078
2005q3	0.817	0.087	2009q4	0.855	0.076	2014q1	0.907	0.081
2005q4	0.815	0.084	2010q1	0.863	0.080	2014q2	0.911	0.081
2006q1	0.834	0.097	2010q2	0.866	0.079	2014q3	0.917	0.076
2006q2	0.836	0.091	2010q3	0.878	0.082	2014q4	0.926	0.067
2006q3	0.833	0.087	2010q4	0.884	0.085	2015q1	0.926	0.063
2006q4	0.826	0.086	2011q1	0.894	0.088	2015q2	0.928	0.064
2007q1	0.838	0.091	2011q2	0.897	0.088	2015q3	0.908	0.066
Overall Mean (2003-2015): 0.867								

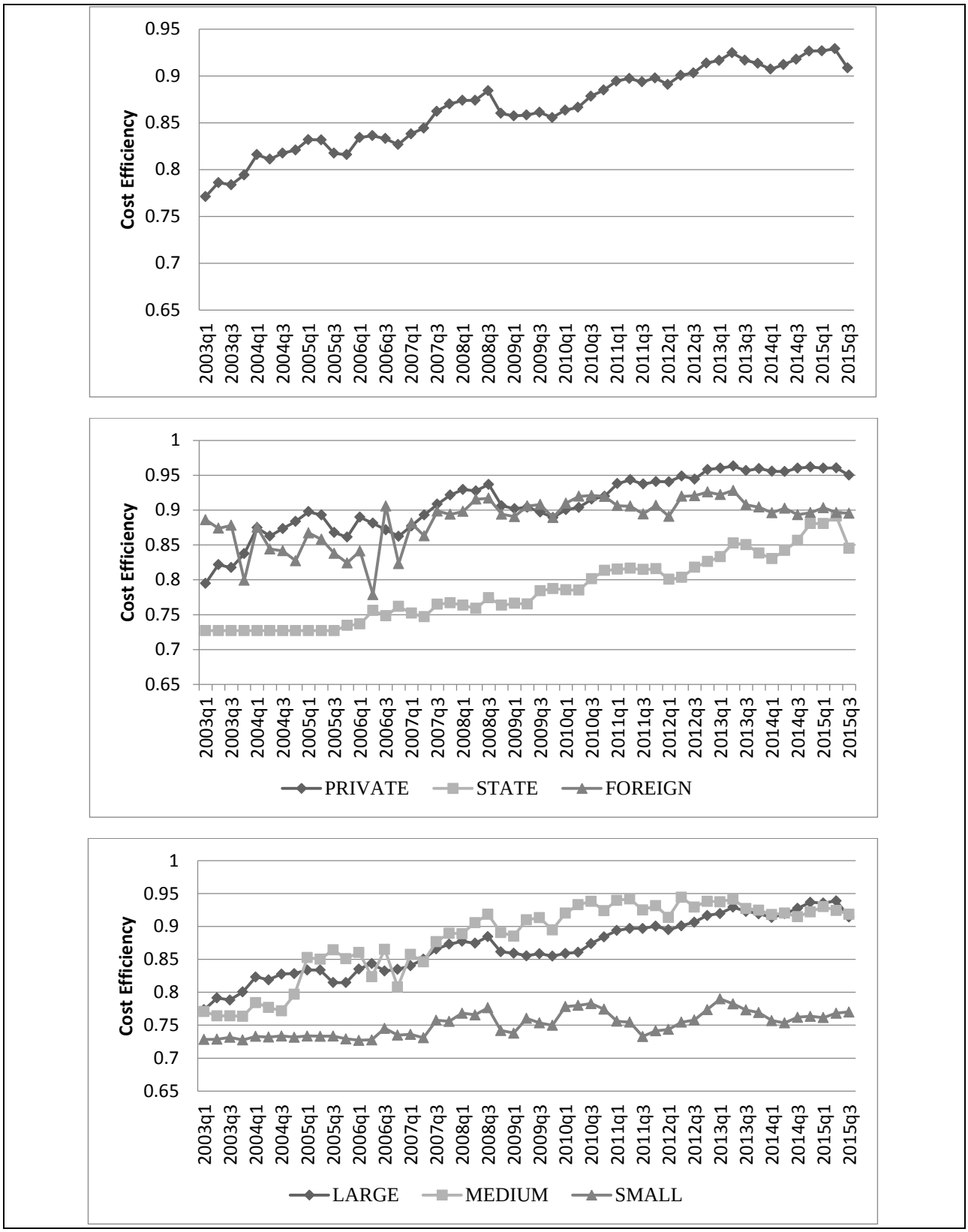

Figure 1: Cost Efficiency Scores from the Selected Model

Similar to many other studies, our next step is examining the efficiency scores across different ownership status. As mentioned before, of our 22 commercial banks 3 are state-owned, 12 are privately-owned domestic and 10 are foreign banks [12]. The second panel of Figure 1 illustrates efficiency scores for three different bank ownership types. It appears that private banks are the most efficient with the average cost efficiency of 91 percent, followed by foreign and state banks with average cost efficiencies of 89 and 78 percent, respectively. This result is in line with the literature for developing countries, where the most common finding is that on average foreign banks are more efficient than or roughly equally efficient to domestic private banks, with both groups being generally more efficient on average than state-owned banks (e.g. Delfino, 2003; Berger et al., 2004; Berger et al., 2005). As discussed in detail by Isik and Hassan (2002) and Berger et al. (2005) there are two main reasons behind the common finding of low cost efficiency of state-owned banks, differences in objectives and budget constraints. While foreign and private banks seek to control its marginal cost and reduce its margins in order to boost its market share and profits, state-owned banks may have no such objectives. State owned banks in developing countries generally pursue objectives set by the government and politicians, such as devoloping specific industries or regions, export expansion, providing patronage jobs or subsidies to politicians' favored constituents. Secondly, the budget constraints of state-owned banks are less strict than those of foreign and private banks since they are frequently supplied by government subsidies or government guaranteed debts. This necessarily leads foreign and private banks to be more efficient by directing investment funds to more efficient places, while state-owned banks might prefer to direct funds to the most politically desirable projects.

Turning to the temporal movement of the efficiency scores for three different bank ownership types, the second panel of Figure 1 clearly illustrates that with the exception of few abrupt changes observed in cost efficiencies of foreign banks during the year 2006, foreign and private banks have relatively similar upward trends until the third quarter of 2008. The

[12] By the end of 2015, average market shares of private, foreign and state banks are 56.6%, 10.2% and 33.1%, respectively. In addition to these numbers, it is noteworthy to provide some information for the temporal change of market shares of private, foreign and state banks over the study period. Although the market share of state banks has followed a gradual decreasing trend over the entire period, temporal movement of market shares of private and foreign banks were exposed to some changes. Over the period 2003-2006, the market share of private banks had an increasing trend, while the market share of foreign banks was relatively stable. Between 2006 and 2008, however, the picture changed with mergers and acquisitions, which resulted in an increase in the market share of foreign banks along with a decline in that of private banks. After 2008, market shares held by foreign and private banks have followed a relatively stable pattern.

exceptional behavior of efficiency scores of foreign banks might result from mergers and acquisitions taken place during 2006. After the third quarter of 2008, the effect of the 2008 global financial crisis became apparent for private and foreign banks with approximately 4 and 3 percentage points declines in efficiency scores, respectively. The recovery lasted for seven quarters for foreign banks, while private banks reached their pre-crisis level after eleven quarters. This finding might suggest that foreign banks, whose parent banks are mainly located in the EU and East Asian countries, were less severely affected by the global financial crisis than domestically owned private banks were. In accordance with the literature, this finding could be attributed to the fact that during episodes of financial turmoil domestic banks might face higher costs of external funding or might be cut off from international financial markets (Efthyvoulou and Yildirim, 2014). Over the period 2011-2015, on the other hand, we observe an ongoing upward trend in the cost efficiencies of private banks coupled with slightly decreasing and relatively stable cost efficiencies of foreign banks. This differentiation could be related to the 2010 European debt crisis. Although the effects of the crisis remained rather limited for Turkish economy as noted by Aysan and Ermisoglu (2013), they were more pronounced, on the average, for foreign banks due to the parent country of the biggest foreign bank being Greece where the debt crisis broke out. Moving on to the efficiency scores of state banks, we observe that a stable path followed over the period 2003-2005 was replaced with a gradual upward trend without being affected by the 2008 global financial crisis.

Next, we proceed with the examination of cost efficiencies of commercial banks for different bank scales. Although found insignificant, it is noteworthy to take a closer look at how bank size affects efficiency scores. As described before, there are 7 large, 5 medium scale and 10 small banks in our sample.[13] The third panel of Figure 1 illustrates weighted average of cost efficiencies for each group of commercial banks. According to the Figure, it seems that medium-sized banks have the highest average cost efficiency of 88 percent, and it is followed by large and small banks with the average cost efficiencies of 87 and 75 percent, respectively. In the empirical literature there is no consensus on the relationship between bank size and efficiency due to conflicting evidences. While some studies report a significantly positive relationship and point to

[13] By the end of 2015, average market shares of large, medium-sized and small banks are 82.1%, 13.5% and 4.3%, respectively. Over the period 2003-2015, all market charges followed a stable path with a slight increase in the market share of medium sized banks coupled with a slight decline in that of large banks.

the efficiency advantage of large banks (e.g. Berger et al., 1993; Ataullah and Le, 2006), some others reveal a significantly negative relationship (e.g. Girardone, Molyneux and Gardener, 2004; Isik and Hassan, 2002; Manlagnit, 2011). A positive relationship is generally attributed to larger banks' market power and high ability to diversify credit risk in an uncertain macroeconomic environment. A negative relationship, on the other hand is related to the complexity of the operations of larger banks and high market discipline of small banks, which face relatively stronger competition than larger banks. Moreover, there are also some studies reporting an unclear or insignificant relationship between bank size and efficiency (e.g. Pi and Timme, 1993; Berger and Mester, 1997; Kasman and Yildirim, 2006).

In our case, although, average cost efficiencies of medium-sized and large banks are approximately same, their temporal movement seems to be different. More specifically, while they moved together by following a similar upward trend from 2003Q1 to 2008Q3, a diversification is observed over the period 2008Q3-2010Q4. With the global financial crisis, the upward trend of cost efficiencies of foreign banks was interrupted and they plummeted by approximately 3 percentage points. Medium-sized banks, on the other hand, appears to be almost unaffected by the crisis. The reason behind this finding could be explained by ownership types of these banks. Out of our 7 large banks, 3 are state-owned and 4 are private. Regarding the ownership types of medium-sized banks, 4 are foreign and only 1 out of 5 is private. Given the previous finding that foreign banks were less severely affected by the global financial crisis than domestically owned private banks were, it is not surprising to observe that the effect of the crisis remained rather limited for medium-sized banks with majority foreign ownership. Over the period 2011-2015, the gap between the efficiency scores of large and medium-sized banks narrowed down until it was closed to almost the same level at 92 percent. Efficiency scores of small banks, on the other hand, followed a relatively stable path with upward and downward cycles fluctuating around its mean level of 75 percent.

5.2. Results from the Model Averaging Approach

As underlined by Huang and Lai (2012), although model selection is frequently employed in empirical studies as a tool to select the best model among the competing ones, different model selection criteria might result in different choices of models and more importantly the selected

model may not be necessarily correct. To circumvent any possible problems, including the model selection and omitted variable biases that may arise from relying on only the single (best) model, Huang and Lai (2012) suggest using a model-averaged estimator, which is a weighted average of estimators obtained from all competing models.

In this respect, to check whether the efficiency scores we derived from the best model selected through the previously discussed search algorithm are exposed to any bias problem or not, we repeat our analysis using the approach of Huang and Lai (2012). In this approach, the efficiency scores are calculated by taking the weighted average of efficiency scores obtained from all 63 estimated cost functions. It is important to specify appropriate weights. Following Huang and Lai (2012), we define the weight of the model *j* as

$$\pi_j{}^{AIC} = \frac{\exp\left(-\frac{1}{2}\Delta_j{}^{AIC}\right)}{\sum_{k=1}^{J}\exp\left(-\frac{1}{2}\Delta_k{}^{AIC}\right)}$$

where $\Delta_j{}^{AIC} = AIC_j - AIC_{\min}$ measures the AIC difference between model *j* and the best model among all *J* competing models. Once the weights are specified, it is straightforward to calculate the model-averaged cost efficiency scores. Figure 2 illustrates these cost efficiencies. Compared to Figure 1, it is clearly seen that the results obtained from the search algorithm are almost identical to those of the model averaging approach, confirming the robustness of our results[14].

[14] We checked for the sensitivity of the model-averaged efficiency scores to alternative information criteria by calculating weights according to the Bayesian information criterion (BIC) of Schwarz, estimated efficiency scores remained almost unchanged.

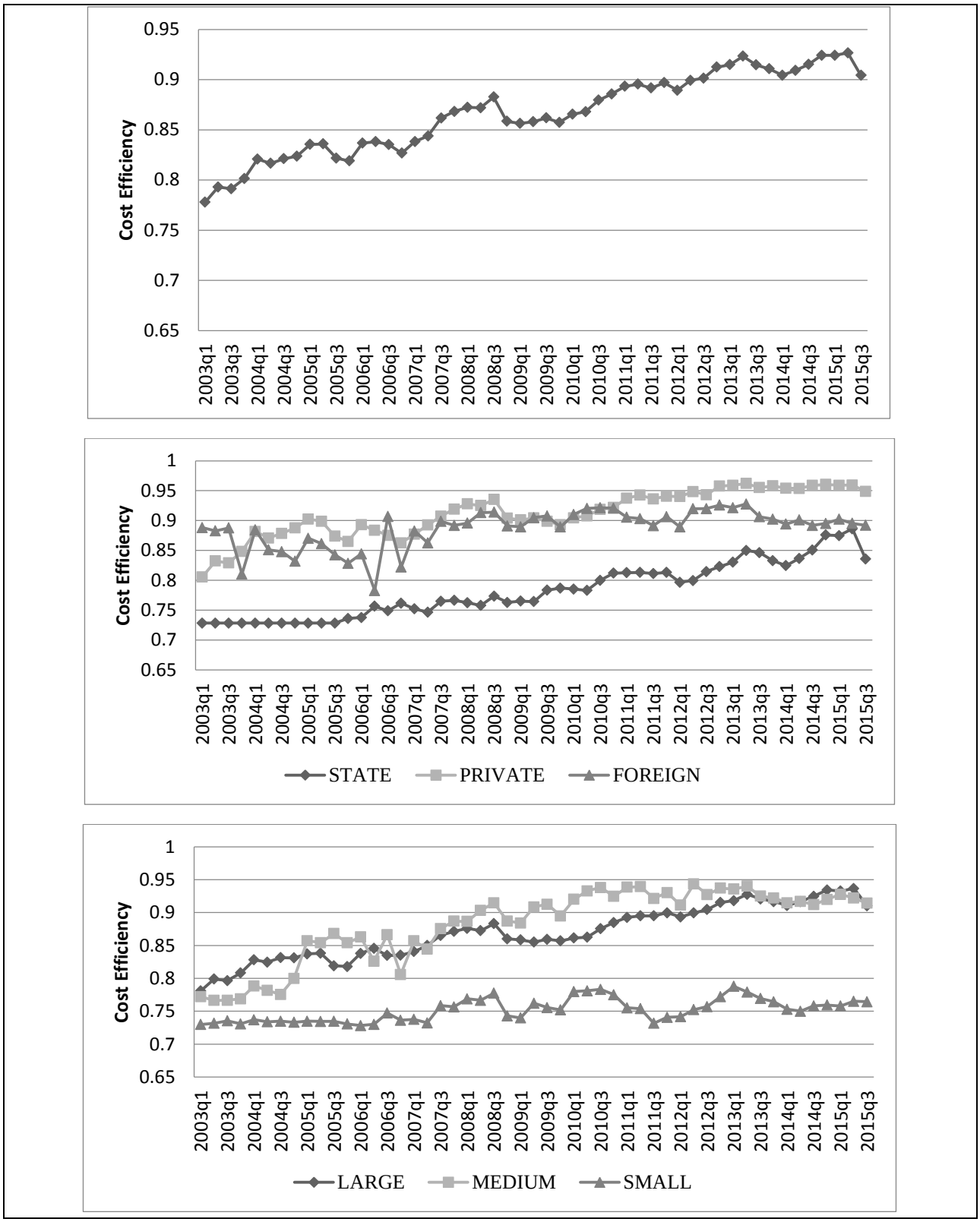

Figure 2: Cost Efficiency Scores from the Model Averaging Approach

5.3. Persistency Analysis for Cost Inefficiency of Turkish Banks

As a final issue, we investigate the degree of persistency in cost inefficiencies of Turkish banks to address the question that whether an inefficient bank becomes efficient or remains inefficient over time. To this end, following Manlagnit (2011), we calculate the Spearman rank correlations for all commercial banks and sub-groups determined by ownership types and scale[15]. The Spearman rank correlations for all commercial banks appear to be statistically significant, suggesting persistency of cost inefficiency of commercial banks. In other words, this finding indicates that if a commercial bank is relatively cost inefficient, then, it is very likely to remain cost inefficient for quite a long period of time. Moreover, our results reveal that inefficiency is persistent for large banks, although it is not so persistent for medium-sized and small banks as the rank correlations are generally statistically insignificant and become negative over time. Regarding banks' ownership types, we observe that cost inefficiencies of private and state-owned banks are quite persistent. For foreign banks, however, correlations appear to be significant only in a few quarters, implying that cost inefficiency is relatively short-lived for foreign banks.

6. Conclusion

This study aims to investigate the cost efficiency of Turkish commercial banks over the restructuring period of the Turkish banking system, which coincides with the 2008 financial global crisis and the 2010 European debt crisis. In this respect, we employ a modified version of the true fixed effect model of Greene (2005), where the unobserved bank heterogeneity is integrated in the inefficiency distribution at a mean level.

Adoption of a search algorithm, which is designed to detect the cost frontier function with the most appropriate inefficiency correlates, justifies that intermediation ratio, capital ratio and the natural logarithm of total assets are effective on measured cost inefficiency, with the direction of the effects being in accordance with our priori expectations. Following estimation, the cost efficiency scores are calculated. Overall, our findings confirm that Turkish banks have

[15] Sparkman rank correlation matrices are not reported here to conserve space, however, interested readers may request the matrices from the authors.

experienced on the average a positive efficiency change during the period 2003-2008, suggesting that the restructuring program fulfills its promise in terms of improving bank efficiency. Moreover, although the negative effect of the 2008 global financial crisis was felt, a relatively quick recovery is observed at the end of 2010. We further observe that 2010 European debt crisis had no noticeable impact on the Turkish banking system in terms of average cost efficiency.

The main findings regarding the analysis of the efficiency scores across different ownership types suggest that on average foreign banks are roughly equally efficient to domestic private banks, with both groups being more efficient than state-owned banks. In accordance with much of the existing literature, the relatively low efficiency of the state-owned banks can be attributed to the differences in their objectives and budget constraints. One of our striking finding is that although the effect of the 2010 European debt crisis remained rather limited for Turkish banking system, it was more noticeable for foreign banks possibly due to the parent country of the biggest foreign bank located in Turkey being Greece where the debt crisis broke out. Regarding the efficiency scores across different bank scales, on the other hand, it is evident that small banks tend to have lower cost efficiency on average than medium-sized and large banks.

To check whether the efficiency scores we derived from the best model selected through the search algorithm are exposed to any model selection bias or not, we repeat our analysis by adopting the model-averaging approach of Huang and Lai (2012). The results obtained from the search algorithm appear to be almost identical to those of the model averaging approach, confirming robustness of our results. Finally, we investigate the degree of persistency in cost inefficiencies of Turkish banks through the Spearman rank correlations. Overall, our results suggest persistency of cost inefficiency of commercial banks, implying that if a commercial bank is relatively cost inefficient, then, it is very likely to remain cost inefficient for quite a long period of time.

References

Aigner, D. J., Lovell C. A. and Schmidt, P. (1977). "Formulation and estimation of stochastic frontier production function models". *Journal of Econometrics*, 6, 23-37.

Akın, G. G., Aysan, A. F. and Yildiran, L. (2009). "Transformation of the Turkish financial sector in the aftermath of the 2001 crisis". *Turkey and the Global Economy: Neo-Liberal Restructuring and Integration in the Post-Crisis Era*, *73*.

Almanidis, P. (2013). "Accounting for heterogeneous technologies in the banking industry: a time-varying stochastic frontier model with threshold effects". *Journal of Productivity Analysis*, 39, 191-205.

Altunbas, Y., Evans, L. and Molyneux, P. (2001). "Bank ownership and efficiency". *Journal of Money, Credit and Banking*, 33 (4), 926-954.

Amidu, M. and Wolfe, S. (2013). "Does bank competition and diversification lead to greater stability? Evidence from emerging markets". *Review of Development Finance*, 3 (3), 152-166.

Assaf, A. G., Matousek, R. and Tsionas, E. G. (2013). "Turkish bank efficiency: Bayesian estimation with undesirable outputs". *Journal of Banking & Finance*, 37 (2), 506-517.

Aysan, F. A. and Ceyhan, S. P. (2008). "What determines the banking sector performance in globalized financial markets? The case of Turkey". *Physica A: Statistical Mechanics and its Applications*, 387 (7), 1593-1602.

Aysan, F. A. and Ermisoglu, E. (2013a). "Eurozone debt crisis and its effects on Turkish economy". MPRA Paper No. 50501.

Aysan, F. A. and Ermisoglu, E. (2013b). "Turkey's capital market and banks: Recipe for survival in recessionary times". MPRA Paper No. 50503.

Ataullah, A. and Le, H. (2006). "Economic reforms and bank efficiency in developing countries: the case of the Indian banking industry". Applied Financial Economics, 16 (9), 653-663.

Banerjee, B. (2012). "Banking sector efficiency in new EU member states". *Eastern European Economics*, 50 (6), 81-115.

Banker, R. D., Chang, H. and Seok-Young, L. (2011). "Differential impact of Korean banking system reforms on bank productivity". *Journal of Banking and Finance*, 34 (7), 1450-1460.

Banking Regulation and Supervision Agency. (2001). "Towards a sound Turkish banking system".

Battese, G. E. and Coelli, T. J. (1995). "A model for technical efficiency effects in a stochastic frontier production for panel data". *Empirical Economics*, 20, 325-332.

Ben-Khedhiri, H., Casu, B. and Naceur, S. B. (2011). "What drives the performance of selected MENA banks? A meta-frontier analysis". *IMF Working Papers*, 11/34.

Berger, A. N. and Humphrey, D. B. (1992). "Measurement and efficiency issues in commercial banking, in Output Measurement in the Service Sectors". (Ed.) Z. Griliches, *The University of Chicago Press*, Chicago, 245-479.

Berger, A. N., Hancock, D. and Humphrey, D. B. (1993). "Bank efficiency derived from the profit function". *Journal of Banking and Finance*, 17 (2), 317-347.

Berger, A. N. and Mester, L. J. (1997). "Inside the black box: What explains differences in the efficiencies of financial institutions? ". *Journal of Banking and Finance*, 21 (7), 895-947.

Berger, A. N. and Humphrey, D. B. (1997). "Efficiency of financial institutions: International survey and directions for future research". *European Journal of Operational Research*, 98 (2), 175-212.

Berger, A. N., Demirgüç-Kunt, A., Levine, R. and Haubrich, J. G. (2004). "Bank Concentration and Competition: An Evolution in the Making". *Journal of Money, Credit and Banking*, 36 (3), 433-451.

Berger, A. N., Clarke, G. R. G., Cull, R., Klapper, L. and Udell, G. F. (2005). "Corporate governance and bank performance: A joint analysis of the static, selection, and dynamic effects of domestic, foreign, and state ownership". *Journal of Banking and Finance*, 29 (8), 2179-222.

Bos, J. W. B., Koetter, M., Kolari, J. W. and Kool, C. J. M. (2009). "Effects of heterogeneity on bank efficiency scores". *European Journal of Operational Research*, 195, 251-261.

Carvallo, O. and Kasman, A. (2005). "Cost efficiency in the Latin American and Caribbean banking systems". *Journal of International Financial Markets, Institutions and Money*, 15, 55-72.

Charnes, A., Cooper, W. W. and Rhodes, E. (1978). "Measuring the efficiency of decision making units". *European Journal of Operations Research*, 2 (6), 429-444.

Chen, T. (2002). "A Comparison of Chance-Constrained DEA and Stochastic Frontier Analysis: Bank Efficiency in Taiwan". *Journal of the Operational Research Society*, 53 (5), 492-500.

Cornwell, C., Schmidt, P., and Sickles, R. (1990). "Production frontiers with cross-sectional and time series variation in efficiency levels". *Journal of Econometrics*, 46, 185-200.

Delfino, M.E., 2003. Bank ownership, privitisation and efficiency: Empirical evidence from Argentina. Working paper, University of Warwick.

Demir, N., Mahmud, S. F. and Babuscu, S. (2005). "The technical inefficiency effects of Turkish banks after financial liberalization". *The Developing Economies*, 43 (3), 396-411.

Denizer, C., Dinc, M. and Tarimcilar, M. (2007). "Financial liberalization and banking efficiency: evidence from Turkey". *Journal of Productivity Analysis* 27, 177–195.

Du, J. and Girma, S. (2011). "Cost economies, efficiency and productivity growth in the Chinese banking industry: evidence from a quarterly panel dataset". *Empirical Economics*, 41, 199-226.

Efthyvoulou, G. and Yildirim, C. (2014). "Market power in CEE banking sectors and the impact of the global financial crisis". *Journal of Banking and Finance*, 40, 11-27.

El-Gamal, M. and Inanoglu, H. (2005). "Inefficiency and heterogeneity in Turkish banking: 1990-2000". *Journal of Applied Econometrics*, 20, 641-664.

Ertugrul, A. and Zaim, O. (1999). "Economic crises and efficiency in Turkish banking industry". *METU Studies in Development*, 26, 99–116.

Fries, S. and Taci, A. (2005). "Cost efficiency of banks in transition: Evidence from 289 banks in 15 post-communist countries". *Journal of Banking and Finance*, 29 (1), 55-81.

Fukuyama, H. and Matousek, R. (2011). "Efficiency of Turkish banking: two stage network system. Variable returns to scale model". *Journal of International Financial Markets, Institutions and Money*, 21 (1), 75-91.

Girardone, C., Molyneux, P. and Gardener, E. P. M. (2004). "Analysing the determinants of bank efficiency: the case of Italian banks". Applied Economics, 36 (3), 215-227.

Greene, W. (1990). "A gamma-distributed stochastic frontier model". *Journal of Econometrics*, 46, 141-163.

Greene, W. (2004). "Disiguishing between heterogeneity and inefficiency: stochastic frontier analysis of the World Health Organization's panel data on national health care systems". *Health Economics*, 13, 959-980.

Greene, W. (2005), "Fixed and random effects in stochastic frontier models". *Journal of Productivity Analysis*, 23, 7-23.

Hao, J., Hunter, W. C. and Kang, W. K. (2001). "Deregulation and efficiency: the case of private Korean banks". *Journal of Economics and Business*, 53 (2), 237-254.

Hasan, I. and Marton, K. (2003). "Development and efficiency of the banking sector in a transitional economy: Hungarian experience". *Journal of Banking and Finance*, 27 (12), 2249-2271.

Huang, C. J. and Lai, H. (2012). "Estimation of stochastic frontier models based on multimodel inference". *Journal of Productivity Analysis*, 38 (3), 273-284.

Isik, I. and Hassan, M. K. (2002). "Technical, scale and allocative efficiencies of Turkish banking industry". *Journal of Banking and Finance*, 26, 719-766.

Jondrow, J., Lovell., C. A. K., Materov, I. S. and Schmidt, P. (1982). "On the estimation of technical inefficiency in the stochastic production function model". *Journal of Econometrics*, 19 (2-3), 233-238.

Kasman, A. (2002). "Cost efficiency, scale economies and technological progress in Turkish banking". *Central Bank Review*, 1, 1-20.

Kasman, A. and Yildirim, C. (2006). "Cost and profit efficiencies in transition banking: the case of new EU members". *Applied Economics*, 38 (9), 1079-1090.

Kasman, A. and Kirbas-Kasman, S. (2006). "Technical change in banking: Evidence from transition countries". *International Journal of the Economics of Business*, 13 (1), 129-144.

Kasman, A., Kasman, S. and Turgutlu, E. (2011). "Testing profit and structure relationship in the European banking markets using efficiency measures". *The Developing Economies*, 49 (4), 404-428.

Kasman, S. and Kasman, A. (2011). "Efficiency, Productivity and stock performance: evidence from the Turkish banking sector". *Panoeconomicus*, 3, 355-372.

Kauko, K. (2009). "Managers and efficiency in banking". *Journal of Banking and Finance*, 33 (3), 546-556.

Koetter, M. and Wedow, M. (2010). "Finance and growth in a bank based economy: is it quantity or quality that matters?". *Journal of International Money and Finance*, 29 (8), 1529-1545.

Kumbhakar, S., 1990. "Production frontiers, panel data and time-varying technical inefficiency". *Journal of Econometrics*, 46, 201–212.

Kumbhakar, S. and Lovell, C. A. K. (2000). "Stochastic Production Frontiers". Cambridge: Cambridge University Press.

Kumbhakar, S. C. and Wang, D. (2007). "Economic reforms, efficiency and productivity in Chinese banking". *Journal of Regulatory Economics*, 32, 105-129.

Manlagnit, M. C. V. (2011). "Cost efficiency, determinants, and risk preferences in banking: A case of stochastic frontier analysis in the Philippines". *Journal of Asian Economics*, 22, 23-35.

McAllister, P. H. and McManus, D. (1993). "Resolving the scale efficiency puzzle in banking". *Journal of Banking and Finance*, 2 (3), 389-405.

Meeusen, W and van den Broeck, J. (1977). "Efficiency estimation from Cobb-Douglas production functions with composed error". *International Economic Review*, 18, 435-444.

Mester, L. J. (1996). "A study of bank efficiency taking to account risk-preferences". *Journal of Banking and Finance*, 20, 1025-1045.

Mester, L. J. (1997). "Measuring efficiency at U.S. banks: Accounting for heterogeneity is important". *European Journal of Operational Research*, 98, 230-242.

Mitchell, K. and Onvural, N. M. (1996). "Economies of Scale and Scope at Large Commercial Banks: Evidence from the Fourier Flexible Functional Form". *Journal of Money, Credit and Banking*, 28 (2), 178-199.

Onis, Z. (1995). "The effect of financial liberalization on the efficiency of Turkish commercial banks". *Applied Financial Economics*, 5, 257–264.

Ozkan-Gunay, E. N. and Tektas, A. (2006). "Efficiency analysis of the banking sector in precrisis and crisis period: A DEA approach". *Contemporary Economic Policy*, 24 (3), 418-431.

Ozkan-Gunay, E. N. (2012). "Risk incorporation and efficiency in emerging market banks during the global crisis: evidence from Turkey, 2002-2009". *Emerging Markets Finance and Trade*, 48 (5), 91-102.

Ozkan, S., Balsari, C. K. and Varan, S. (2014). "Effect of banking regulation on performance: Evidence from Turkey". *Emerging Markets Finance and Trade*, 50 (4), 196-211.

Pi, L. and Timme, S. G. (1993). "Corporate control and bank efficiency". *Journal of Banking and Finance*, 17 (2), 515-530.

Poghosyan, T. and Kumbhakar, S. C. (2010). "Heterogeneity of technological regimes and banking efficiency in former socialist economies". *Journal of Productivity Analysis*, 33, 19-31.

Rao, A. (2005). "Cost frontier efficiency and risk-return analysis in an emerging market". *International Review of Financial Analysis*, 14 (3), 283-303.

Sealy, C. W. and Lindley, J. (1977). "Inputs, outputs and a theory of production and cost at depository financial institutions". *Journal of Finance*, 32, 1252–1266.

Wang, H. and Schmidt, P. (2002). "One-Step and Two-Step Estimation of the Effects of Exogenous Variables on Technical Efficiency Levels". *Journal of Productivity Analysis*, 18 (2), 129-144.

Wang, D. and Kumbhakar, S. C. (2009). "Strategic groups and heterogeneous technologies: an application to the US banking industry". *Macroeconomics and Finance in Emerging Market Economies*, 2 (1), 31-57.

Williams, J. (2012). "Efficiency and market power in Latin American banking". *Journal of Financial Stability*, 8 (4), 263-276.

Yildirim, C. (2002). "Evolution of banking efficiency within an unstable macroeconomic environment: the case of Turkish commercial banks". *Applied Economics*, 34, 2289-2301.

Zaim, O. (1995). “The effect of financial liberalization on the efficiency of Turkish commercial banks”. *Applied Financial Economics*, 5, 257-264.